THE FORAGING ECOLOGY OF EMPEROR PENGUINS (*APTENODYTES FORSTERI*) AT TWO MAWSON COAST COLONIES, ANTARCTICA

by

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STATEMENT OF ORIGINALITY

Except where otherwise stated, the work in this thesis is my own. The work contains no material which has been accepted for the award of any other higher degree at any tertiary institution.

Graham G. Robertson.

AUTHORITY OF ACCESS

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Graham G. Robertson
(5 March 1995)

Quintessential Antarctica: Auster emperor penguin colony in mid-winter, showing milky-blue grounded ice bergs, pink twilight skies and 11,000 male emperor penguins (and a few distracted individuals) huddling for shared warmth.

ODE TO AN EMPEROR

(originally to a mouse)

I'm truly sorry man's dominion
has broken nature's social union
An' justifies the ill opinion
which makes thee startle
At me, thy poor earth-born companion
An' fellow mortal

- Robbie Burns (1785)

ABSTRACT

1. The foraging ecology of emperor penguins was examined at two colonies on the Mawson Coast of Antarctica during the winter, spring and summer of 1988. The study sought to quantify the penguin's reproductive performances and chick mortality schedules, chick diet composition, energy intake and food consumption of adults and chicks, and adult hunting performance during the period of chick care .

2. Several techniques commonly used for conducting ecological research on penguins were modified for use on emperors. These included techniques for: capture and restraint, measuring body masses, marking individuals for identification, sampling stomach contents, preventing liquid radio-isotopes from freezing in sub zero temperatures, handling adults during incubation and brooding, withdrawing blood samples and attaching dive recorders. The techniques are of particular relevance to field research conducted during the Antarctic winter.

3. The population size and breeding success of emperor penguins at the Auster and Taylor Glacier colonies was estimated from winter photographs of incubating males and collections of abandoned eggs and dead chicks. At Auster a total of 10,963 pairs produced about 6,350 fledglings for a breeding success of 58%. At Taylor Glacier about 2,900 pairs raised 1,774 fledglings for a breeding success of 61%. Fledglings left Taylor Glacier over a period of 33 days at a mean mass of 10.56 kg.

4. A validation study was conducted on the tritiated water (HTO) and sodium-22 (^{22}Na) turnover methods as estimators of dietary water and sodium intake by free-ranging emperor penguins. Penguins assimilated 76.2% and 81.8% of available energy in squid and fish diets, respectively. Both isotopes had equilibrated with body water and exchangeable sodium pools by 2 h after intramuscular injection. The tritium method yielded reliable results after blood isotope levels had declined by 35%. On average the tritium method underestimated water intake by 2.9%, with a range of -10.3% to +11.1%. The ^{22}Na method underestimated Na intake on average by 15.9% with the errors among individuals ranging from -37.2% to -1.8%. Discrepancies with ^{22}Na turnover were significantly greater with the squid diet than the fish diet. The results confirm the reliability of the tritium method as an estimator of food consumption by free-living emperor penguins (provided sea water and fresh water ingestion is known) and support the adoption of the ^{22}Na method

to derive an approximation of sea water intake by tritiated emperor penguin chicks, and by tritiated adults on foraging trips of short duration.

5. The diet composition of emperor penguin chicks was examined at Auster and Taylor Glacier colonies by water-offloading adults serially between hatching in mid-winter and fledging in mid-summer. Chicks at both colonies consumed a similar suite of prey species. Crustaceans occurred in 82% of stomach samples at Auster and 87% of stomachs at Taylor Glacier and were heavily digested; their contribution to food mass could not be quantified. Fish, primarily bentho-pelagic species, accounted for 52% by number and 55% by mass of chick diet at Auster and squid formed the remainder. At Taylor Glacier the corresponding values were 27% by number and 31% by mass of fish and 73% by number and 69% by mass of squid. Of the 33 species or taxa identified the fish *Trematomus eulepidotus* and the squid Psychroteuthis glacialis and *Alluroteuthis antarcticus* accounted for 64% and 74% of the diets by mass at Auster and Taylor Glacier respectively. The sizes of fish varied temporally but not in a linear manner from winter to summer. Adult penguins captured fish ranging from 60 mm (*Pleuragramma antarcticum*) to 250 mm (*T. eulepidotus*) in length and squid (*P. glacialis*) from 19 mm to 280 mm mantle length. The length-frequency distribution of *P. glacialis* showed seasonal variation with the size of squid increasing from winter to summer. The energy density of chick diet mix increased significantly prior to fledging.

6. The energy requirements and food consumption of emperor penguin chicks during their 150-day development was studied at Auster and Taylor Glacier colonies by means of doubly labelled water ($^3H_2{}^{18}0$)-derived estimates of field metabolism and measurement of tissue energy accumulation during growth. Growth rates to asymptotic mass ranged from 19 $g.d^{-1}$ for brooded chicks to 74 $g.d^{-1}$ for chicks mid-way through their development. Tritiated water derived feeding rates ranged from 199 $g.kg^{-1}.d^{-1}$ for brooded chicks to 44 $g.kg^{-1}.d^{-1}$ for pre-departure fledglings, which were fed a sub-maintenance ration following attainment of asymptotic mass. Mass-specific field metabolic rates declined from 583 $kJ.kg^{-1}.d^{-1}$ for chicks weighing about 1 kg to 323 $kJ.kg^{-1}.d^{-1}$ for chicks near to asymptotic mass (c 12 kg). Field metabolism scaled on body mass was best described by $FM = 0.446\ M^{0.91}$ ($r^2 = 0.74$; $n = 32$), where FM is field metabolism ($MJ.d^{-1}$) and M is chick mass (kg). The relationship was statistically indistinguishable from tritiated water-derived estimates of FM for chicks fed a ration suitable for maintenance (growth excluded) only. An 'average' chick expended a total of 444 MJ metabolized energy during development, which consisted of 125 MJ accumulated in new tissue and 319 MJ

expended for maintenance. Food intake to satisfy total metabolized energy was 84 kg, which represents the amount of food required to produce an emperor penguin chick from hatching to independence. Based on this estimate and knowledge of chick diet composition, chicks at Auster and Taylor Glacier colonies consumed an estimated 648 tonnes and 290 tonnes of food, respectively, during the 1988 breeding season.

7. The food and energy requirements of adult emperor penguins parenting chicks were examined at Auster (about 11,000 pairs) and Taylor Glacier (about 2,900 pairs) colonies during the winter, spring and summer of 1988. Tritiated water-derived estimates of adult food consumption trebled during the five-month period of chick care. For birds at sea, estimates ranged from 89 $g.kg^{-1}.d^{-1}$ (2.3 $kg.d^{-1}$) in winter when chicks were < 5 % of adult mass, to 259 $g.kg^{-1}.d^{-1}$ (6.3 $kg.d^{-1}$) in summer, when chicks represented 40 - 50% of adult mass. These food consumption rates were equivalent to the acquisition of 440 $kJ.kg^{-1}.d^{-1}$ (11.4 $MJ.d^{-1}$) and 1,380 $kJ.kg^{-1}.d^{-1}$ (33.4 $MJ.d^{-1}$) metabolizable energy in winter and summer respectively. Chick provisioning was not accompanied by a major increase in food consumption by adults. Adults assimilated 85-92% of their daily food intake themselves and retained the remainder for the chick. The food ration of chicks for the three seasons (648 tonnes at Auster) constituted only about 6% of the total food intake by the adults during the same period. In spite of this, adults appeared to be operating near their maximum food gathering capacity when raising chicks. Adults consumed an estimated 482 kg of food (including the ration for the chick), which amounts to about 10,615 tonnes and 2,800 tonnes of fish and squid consumed by the breeding populations at Auster and Taylor Glacier, respectively.

8. The diving performance of adult emperor penguins was examined in winter, early spring, late spring and summer. These seasons coincided with the brood, creche, mid-growth and pre-fledging stages of chick development, respectively. The distribution in the water column of modal depths did not appear to be affected by season. Mean maximum dive depth (53-66 metres) was similar for all four seasons, as was mean maximum dive duration (2.8-4.1 minutes). Maximum depths and durations of individuals in the four groups ranged from 130-460 metres and from 6.2-22.0 minutes, respectively. Diving was restricted to daylight and twilight, and dive rate increased as day length increased, from 64.1 ± 26.9 dives/day in winter to 131 dives/day in summer (one individual). Deep dives occurred at any time of the day, not only during periods of peak light intensity. The large proportion of bentho-pelagic prey in the emperors' diet, combined with knowledge of their dive

patterns, suggests the emperors' hunted prey in the meso-pelagic region of the water column, including on the sea bottom of the continental shelf. The penguins' prey composition, prey habitat, marine topography, seasonal changes in the fast-ice and the birds' diving performances are used to make some basic estimates of the foraging locations and prey capture rates of emperor penguins.

ACKNOWLEDGEMENTS

This study would not have taken place without the initiative and foresight of Harry Burton and the late Dr. Gavin Johnstone, both of the Australian Antarctic Division. It was Harry and Gavin's idea that the Division commence a study on emperor penguins and that it should be located on the Mawson Coast, one of the most ideal places in Antarctica to conduct overwintering studies on emperors. I am grateful to Harry and Gavin for giving me the freedom in the initial stages of the study to rationalise the various themes to be addressed, and for the opportunity to conduct the field program and compile this thesis.

The emperor penguin is the largest seabird and since it is the only species of bird to breed through the severe Antarctic winter and spring it is arguably the most difficult seabird to study. Although I had spent 14 years conducting field work in the Australian arid zone before going to Mawson, the work on the emperors was undoubtedly the most difficult field work I had ever conducted. The difficulties that arose were mainly due to the logistical problems of conducting an extensive ecological study on emperors in the dim light and cold of winter, and the newness of some of the more intrusive aspects of the program. Within this context, it is important to stress that the extent to which the program was successful was largely a product of the unstinting support afforded by the 24 people with whom I overwintered. These expeditioners are too numerous to mention by name, so I thank them all collectively. A few, however, cannot remain nameless. Deserving of special thanks are Phil Barnaart, Dave McCormack and Tony Everett for the pivotal roles they played in the program. Phil, the station leader, not only assisted in the field but did a great deal at the station, sight unseen by me, to ensure the field program ran smoothly. Dave and Tony, both tradesmen, between them have spent eight winters in Antarctica and their knowledge of the sea-ice and the weather, and the interplay between the latter and the logistical side of the emperor work, reduced my learning curve to a minimum and cut my mistake rate to a tolerable level.

I am grateful to Arthur Alexander, a diesel mechanic, for the 2.5 months he spent helping in the field on this project and for his capacity to work at any hour of the day and in all weather conditions, no matter how atrocious. I also thank him for his tolerance during the seven weeks we worked alone together at Taylor Glacier at the end of the study, when for reasons unknown to both of us our capacity to

maintain civil lines of communication fell dismally short of optimal levels. That the data collection continued unabated testifies to Arthur's commitment to the emperor program and his utility as an Antarctic expeditioner.

I am grateful to Brian Green and Keith Newgrain, both from the CSIROs Division of Wildlife and Ecology, and to Roger Handsworth, of Platypus Engineering. Much of what I know about isotope dilution work on seabirds I learnt from Brian and Keith and I thank them both for their contributions during the formative stages of the study and for their advice during the extensive laboratory work that resulted from the field program. Roger, in consultation with Harry Burton and myself, designed and built the electronic time-depth recorders used during the study and wrote the software to analyse the penguin dive records. The winter deployment of time-depth recorders on emperors was pioneering work and carried considerable risk of failure, given the likely effect of the cold on the microprocessors and power supply, and the potential for the instruments to be damaged when the emperors dived in dense pack-ice. Having neither seen an emperor nor experienced Antarctic conditions, and with minimal time for testing during manufacture, Roger built devices that functioned almost perfectly in all seasons. This 'strike rate' with the emperor work attests to Roger's insightfulness and creativity in the engineering of instruments for use under extreme conditions.

In the formative stages of this project my capacity to answer many of the research questions about the emperors was shrouded in mystery, mainly because much of the work was either new for the species or new for the winter period in which it was conducted. The emperors large size and great strength were problems in theory only, and in practise were mostly offset by the their phlegmatic disposition and general approachability at the colony. Of greater concern was the emperors non-territorial breeding habit, which made finding experimental birds particularly difficult and often traumatic (for both penguin and researcher, due to the effect of disturbance to non-experimental adults and chicks), and the penguins habit of breeding in the darkness and cold of winter.

Emperors rear chicks in five months between mid-winter and mid-summer, and most of the field work took place over this period. During this time emperors conduct all the behaviours that characterise reproduction and care of the young in wind-chill equivalent temperatures that may reach 90°C lower than the body temperature of both the birds and the people studying them. To a person wind-chill equivalent temperatures of -50°C and lower seem incomprehensible, but to an

emperor they are a normal part of living and breeding in the cold. Our inability to comprehend the capacity of emperors to cope in these temperatures reflects the enormity of the gulf between the behavioural and physiological adaptations of emperors and those of ourselves. Unlike the penguins the researcher possesses no natural strategies for survival in the cold and in order to conduct productive field work this gulf must be bridged by creative use of technology.

This is a long winded way of stressing the role played in the program of an apple hut, a set of portable sheep yards, and a hagglunds oversnow vehicle. The apple hut, a 3 metre diameter fibre glass dome, was indispensable for severe weather work on the birds and for people to shelter in during blizzards. Rod Ledingham bought the concept of an apple hut to my attention and made one available for the study. The sheep yards were indispensable for temporarily restraining penguins, an essential activity for most aspects of the study. Without the yards the integrity of the isotope dilution work (Chapters 6 and 7), in particular, would have been seriously compromised. The last serious work at Auster colony took place in the 1950s and relied on sledging dogs as a means of transport. I was fortunate to have at my disposal a hagglunds oversnow vehicle, which was functional and reliable to the point that nearly all one's time and energy could be devoted to the emperor program, rather than to the logistical details of transportation and to devising ways to cope during the next change in the weather.

It is customary in theses such as this to mention near the end of the list of acknowledgements the contribution of one's immediate family, but it would probably be more pertinent if they were listed first, such is the behind-the-scenes contribution they usually make. I am grateful to my wife Debby for releasing me from domestic duties to indulge myself with the emperors, and to daughters Anna and Jacqui for enduring my 14-month absence in Antarctica and my mental detachment from family life in the several intensive months it took to finish the thesis.

I am also grateful to Jenny Cole for her assistance with various aspects of the typing of this thesis, and to my supervisor, Dr David Ritz, for his administrative support at the University, for his critical comments of drafts of each chapter and for his tolerance with the time it took for me to bring this thesis to completion.

Finally, a word about the emperors. In my, moderately biased, opinion Auster emperor penguin colony during winter lies at the epicentre of the experiences on

offer by the Australian Antarctic Research Program. Very few people have the opportunity to overwinter with the emperors and experience first-hand these wonderful, phlegmatic birds at a time of year when they exhibit all the qualities that enable them to thrive on the edge of existence. The experience is powerful enough to puncture the soul of any mortal human, and behoves on those fortunate few, as a kind of pay-back for the emperors tolerance and good grace during experimentation, the responsibility to look out for them in the future when the volatile mix of human attitudes comes to bear on the management of the frozen continent the emperors call home. I hope the particles of insight included in this thesis will contribute to the well being and longevity of all emperor penguin populations in Antarctica.

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CHAPTER 1: INTRODUCTION

With the purpose of setting the stage for the chapters that follow, this section includes a brief description of the emperor penguin yearly cycle, a summary of the present state of knowledge on emperor penguin biology (so the current work can be placed in historical and biological perspective) and the overall aims of the study and structure of the thesis. A systematic review of the literature has not been included in this introduction because the literature on penguins in general, and emperor penguins in particular, has been cited extensively in the appropriate sections of the thesis and to review it again would be unnecessarily repetitive. For this reason the themes of previous studies, rather than the details of their findings, are mentioned below.

The breeding cycle of emperor penguins is only briefly described, because various aspects of the cycle (but not the entire cycle) central to each chapter are summarised in the appropriate sections of the chapters that follow. However, compared to other bird species the annual cycle of emperors is extraordinary, and for the work that follows to be placed in context with respect to the range of activities exhibited by emperors during the course of the year, a description of the penguins' annual calendar is included below.

Understanding of the annual cycle of emperor penguins relies mostly on observations of birds at the Pointe Géologie colony (66°40'S; 140°01'E) as reported by Prévost (1961), Mougin (1966) and Le Maho (1977). The breeding cycle lasts nine months, but extends to a full year when adult pre- and post- breeding maintenance requirements are included. The breeding period is inextricably linked to the annual setting and breaking out of the fast sea-ice on which the penguins establish their colonies, and this places time limits on the extent of the various stages in the annual cycle. For simplicity the cycle can be divided into the summer maintenance period, the autumn pre-nuptial period, the winter incubation period and the chick rearing period.

For birds that bred successfully the previous year, the summer maintenance period begins in late December or early January with a 30 day stint at sea when adults re-build their energy reserves in preparation for the moult. Following the moult, which lasts about 20 days, the birds fatten again at sea in preparation for the pre-